RIA-81-U973
supplement

CONTRACTOR REPORT ARLCD-CR-81017

Supplement

HIGH FRAGMENTATION STEEL PRODUCTION PROCESS

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September 1982

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INTRODUCTION

In order to gain more data on HF-1 steel, two (2) samples were studied at the request of ARRADCOM. One (1) sample was produced by Bethlehem Steel Corporation at their California mill and the other was produced by Crucible Steel.

Both samples were evaluated according to the format in the contractor report ARLCD-CR-81017, MM&T Project 5794189 dated August, 1981.

ACQUISITION OF STEEL

Crucible Steel:

Crucible Steel billets were remnants of steel that was forged at Scranton Army Ammunition Plant for XM795 project and ordered as 5-1/4 inch RCS.

Bethlehem Steel:

Bethlehem Steel samples were pieces shipped to the contractor by Norris Industries, California. The size received was 4 inch RCS.

CHARACTERIZATION

Surface Quality:

Both samples had good surface quality with neither having excessive conditioning (grinding) by their respective mills.

METALLURGICAL EVALUATION

Heat Chemistry:

Samples of both materials were submitted to U. S. Testing for chemical analysis. The ladle chemistry from Bethlehem Steel was not available. The ladle chemistry of Crucible Steel is shown in Table 1.

TABLE 1

LADLE ANALYSIS FROM CRUCIBLE STEEL

C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Al
1.08	1.82	0.023	0.022	0.86	0.13	0.09	0.004	0.03	0.009

U. S. Testing Company was sent samples from both suppliers so that the edge chemistry 0.25 inch beneath the surface could be compared with the chemistry at Mid Radius.

The results of the analysis are shown in Table 2.

TABLE 2 - CHEMISTRY OF MID RADIUS VS EDGE

	% Carbon	% Manganese	% Silicon	
Crucible - Mid Radius	1.20	1.60	0.42	
Crucible - Surface	1.04	1.70	0.44	
Bethlehem XX2L30D Mid Radius	1.10	1.40	0.39	
Bethlehem XX2L30D Surface	1.01	1.45	0.42	
	% Chromium	% Nickel	% Copper	% Molybdenum
Crucible - Mid Radius	0.12	0.11	0.10	0.10
Crucible - Surface	0.13	0.10	0.10	0.10
Bethlehem XX2L30D Mid Radius	0.13	0.11	0.10	0.10
Bethlehem XX2L30D	0.13	0.11	0.11	0.10
	% Aluminum	% Sulfur	%Phosphorus	
Crucible Mid Radius	0.01	0.030	0.012	
Crucible Surface	0.01	0.013	0.014	
Bethlehem XX2L30D Mid Radius	0.01	0.037	0.010	
Bethlehem XX2L30D Surface	0.01	0.018	0.012	

Both samples meet the chemical specification of HF-1 steel. Both steel samples show slight carbon and sulfur segregation.

Segregation:

In order to determine the segregation of both samples, billet sections from both heats were compared to macrographs in MIL-STD-1459A. Both samples were classified as acceptably sound steel. The macrographs are contained in Appendix A for comparison.

The segregation ratings for the subject steel are shown in Table 3. The ratings system consists of an alpha character and a numeral. A - designates center defects; B - subsurface; C - Ring; D - miscellaneous defects. The number designates the severity of the defect, progressing from one to seven, seven being the most severe. Any defect in the D series, except D-2, can be cause for rejection of the steel.

Both samples were etched in a solution of 50% hydrochloric acid and 50% water at 170°F after both samples were ground. Upon comparison with the MIL standard, both were rated as clean and sound.

TABLE 3 - SEGREGATION EVALUATION

Bethlehem Steel	B2	C1	A2
Crucible Steel	B2	C2	A3

Hardenability:

No hardenability data was available for either sample.

BILLET CROSS SECTION HARDNESS PATTERN

A 10 x 10 grid of 1/2 inch squares was inscribed on the Crucible Steel section and a 9 x 9 grid was inscribed on the Bethlehem Steel section. Hardness readings were taken in the Rockwell C range and are reported in Table 4. Actual hardness patterns are included in Appendix B.

TABLE 4 - HARDNESS PATTERN

	RC Mean	BHN
Bethelehm Steel	29.4	280
Cricible Steel	30.2	287

INCLUSIONS (Microcleanliness)

Both samples were evaluated with a Scanning Electron Microscope and EDAX analysis.

TABLE 5 - INCLUSION RATING

	Manganese Sulfide	Calcium Silicate
Bethlehem Steel	2 - Heavy	2 - Heavy
Crucible Steel	1/2 - Thin	1 - Thin

Crucible:

Figure 1 is an SEM photomicrograph of the inclusion from Crubible Steel and Figure 2 in its EDAX evaluation.

CRUCIBLE STEEL

SEM

Inclusion Analysis

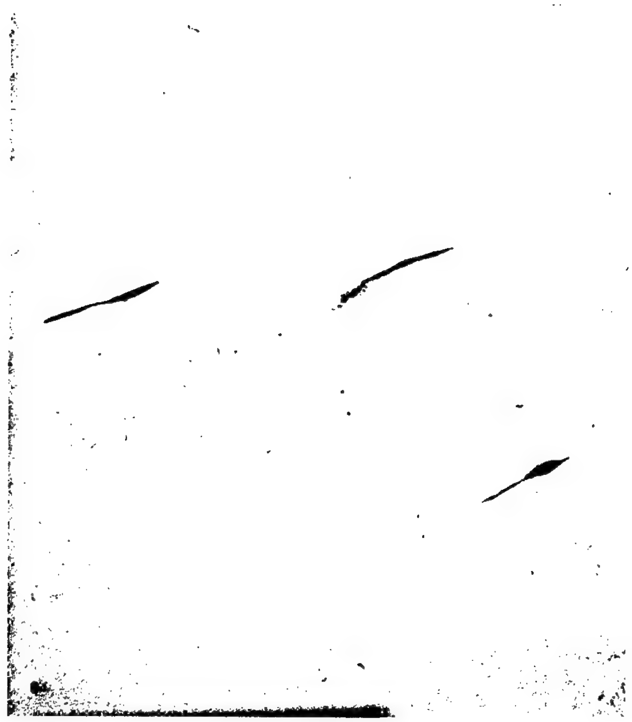
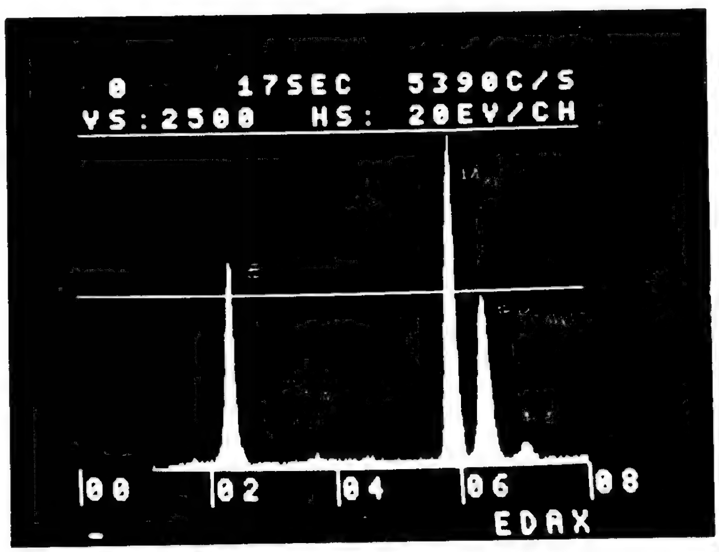


Figure 1 - SEM photomicrograph of typical inclusion.
300X

CRUCIBLE STEEL

SEM

EDAX Evaluation of Inclusions



S Ca Mn Fe Fe

Figure 2 - EDAX Evaluation

Bethlehem Steel:

Figure 3 is an SEM photomicrograph of one type of inclusion found in the sample. It is typical Manganese Sulfide and its EDAX evaluation is depicted in Figure 4.

Figure 5 is an SEM photomicrograph of a round type inclusion. Its EDAX evaluation is illustrated in Figure 6. Its complexity is interesting. It is significantly higher in calcium. This information may be of value when evaluating cause of defects found in the processing stages.

It is thought that the heavier inclusion rating of Bethlehem Steel is due to the difference in melting practice of Bethlehem Steel (BOF) versus Crucible Steel (electric). The difference is not detrimental to obtaining the desired mechanical properties.

MATRIX OF BOTH SAMPLES

Figure 7 is the EDAX evaluation common to both vendors.

FLAME CUT ENDS

Bethlehem Steel flame cut several billets in order to provide sample bars for the contractor to evaluate. One of these flame cut ends was metallographically evaluated and revealed some interesting phenomena. Figure 8 shows the end surface of the billet on the flame cut surface. Figure 9 is the longitudinal section of the cut out in Figure 8. The top area is a layer of white (dendritic) cast iron formed by the absorption of carbon from the torch. The next layer is a section of untempered martensite. In this layer are white areas of retained austenite which are mainly perpendicular to the surface. Special attention should be given to the retained austenite streak in the center of the photomicrograph as it has intergranular cracking propagating from the surface along the austenitic grain boundaries. This crack will never self-weld on forging but will decarburize along its surface and subsequently produce a crack in a forging. Evidence of this was published by the author in a report dated 11 February 1981, entitled "M106, Evaluation of Base Defect".

Figure 10 and 11 are magnified centerline views of the untempered martensite platelets showing unique micro cracking in the platelets.

HEAT TREATMENT

Coupons of both vendors austenitized at 1500°F quenched in oil and tempered at various temperatures. Figures 12 through 15 illustrate the mechanical properties attainable at various tempering temperatures.

BETHLEHEM STEEL

SEM

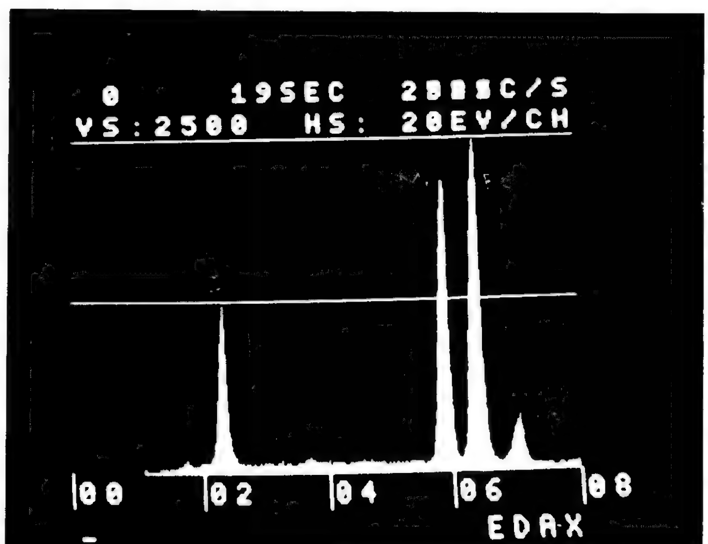
Inclusion Analysis

Figure 3 - SEM photomicrograph of one type of inclusion.
300X

BETHLEHEM STEEL

SEM

Inclusion Evaluation



S Mn Fe Fe

Figure 4 - EDAX Evaluation of inclusion.

BETHLEHEM STEEL

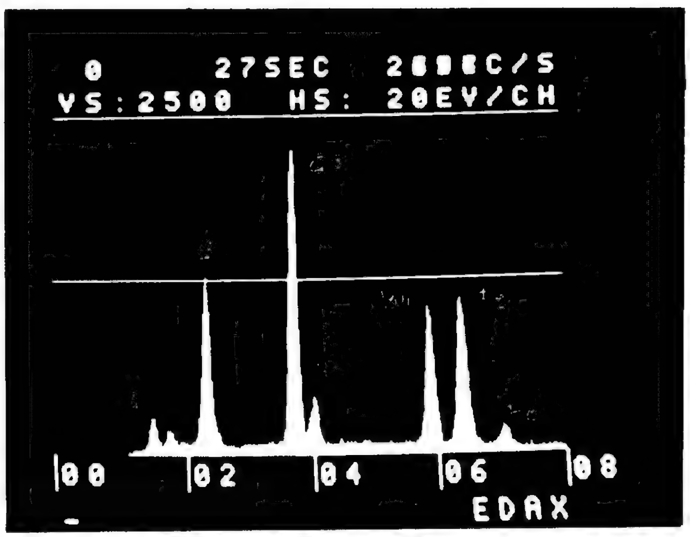
SEM

Figure 5 - SEM photomicrograph of a round type of inclusion. 3000X

BETHLEHEM STEEL

SEM

EDAX Analysis of Inclusion



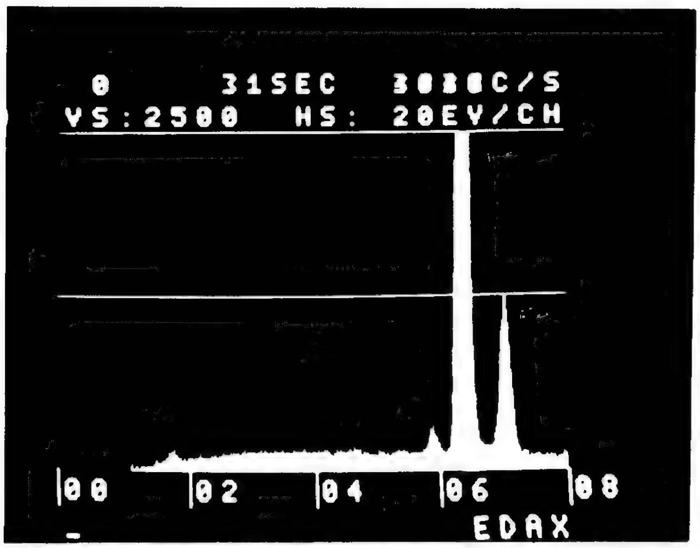
Ai Si S Ca Ca Mn Fe Fe

Figure 6 - EDAX Evaluation of complex round inclusion.

BETHLEHEM STEEL

CRUCIBLE STEEL

EDAX Evaluation of Steel Matrix



Si Mn Fe Fe

Figure 7 - EDAX Evaluation of Matrix common to both vendor material.

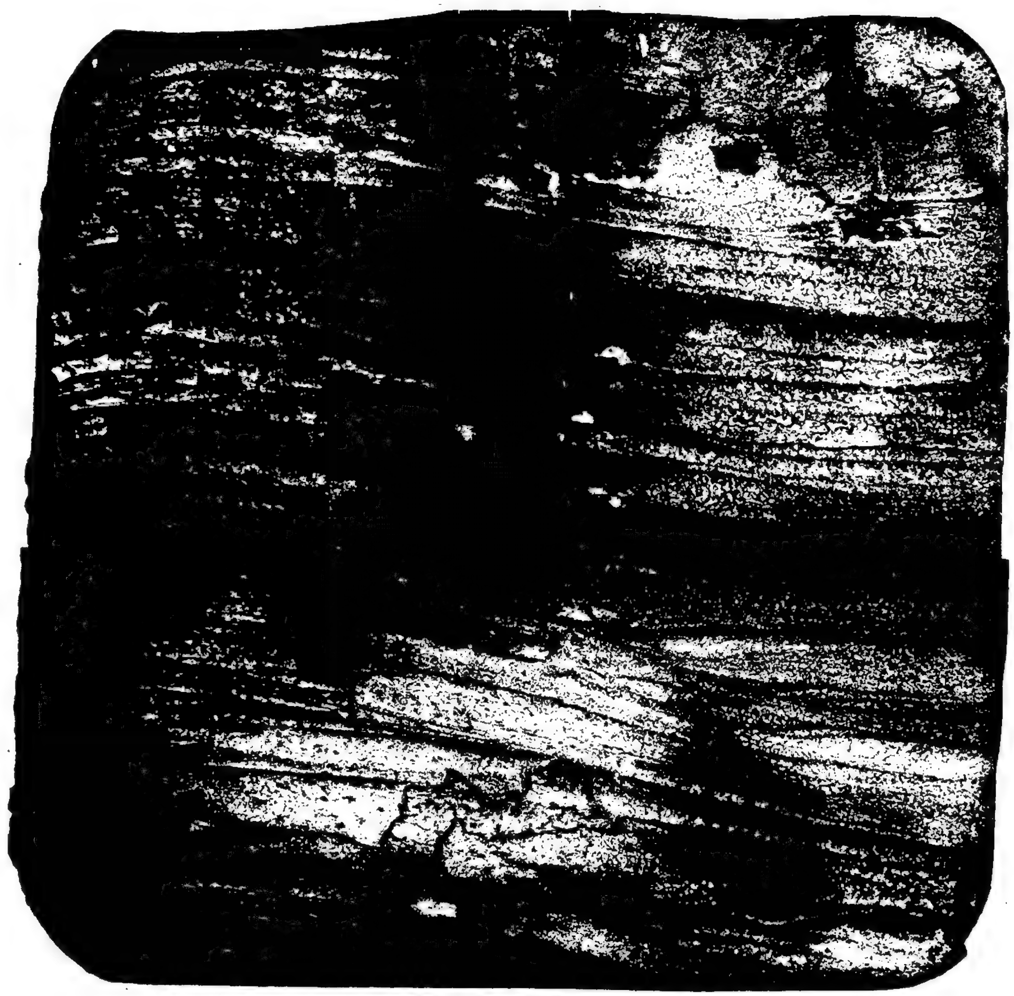


Figure 8 - Photomacrograph of flame cut surface. 1X

Figure 9 - Photomicrograph of longitudinal section of flame cut area. 63X

<u>BETHLEHEM STEEL</u>

<u>Flame Cut Evaluation</u>

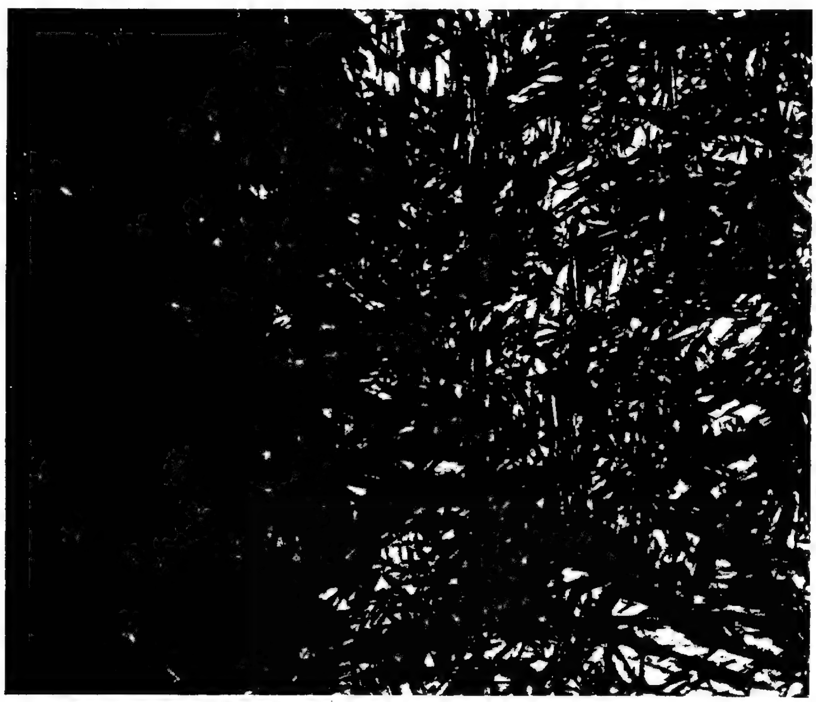


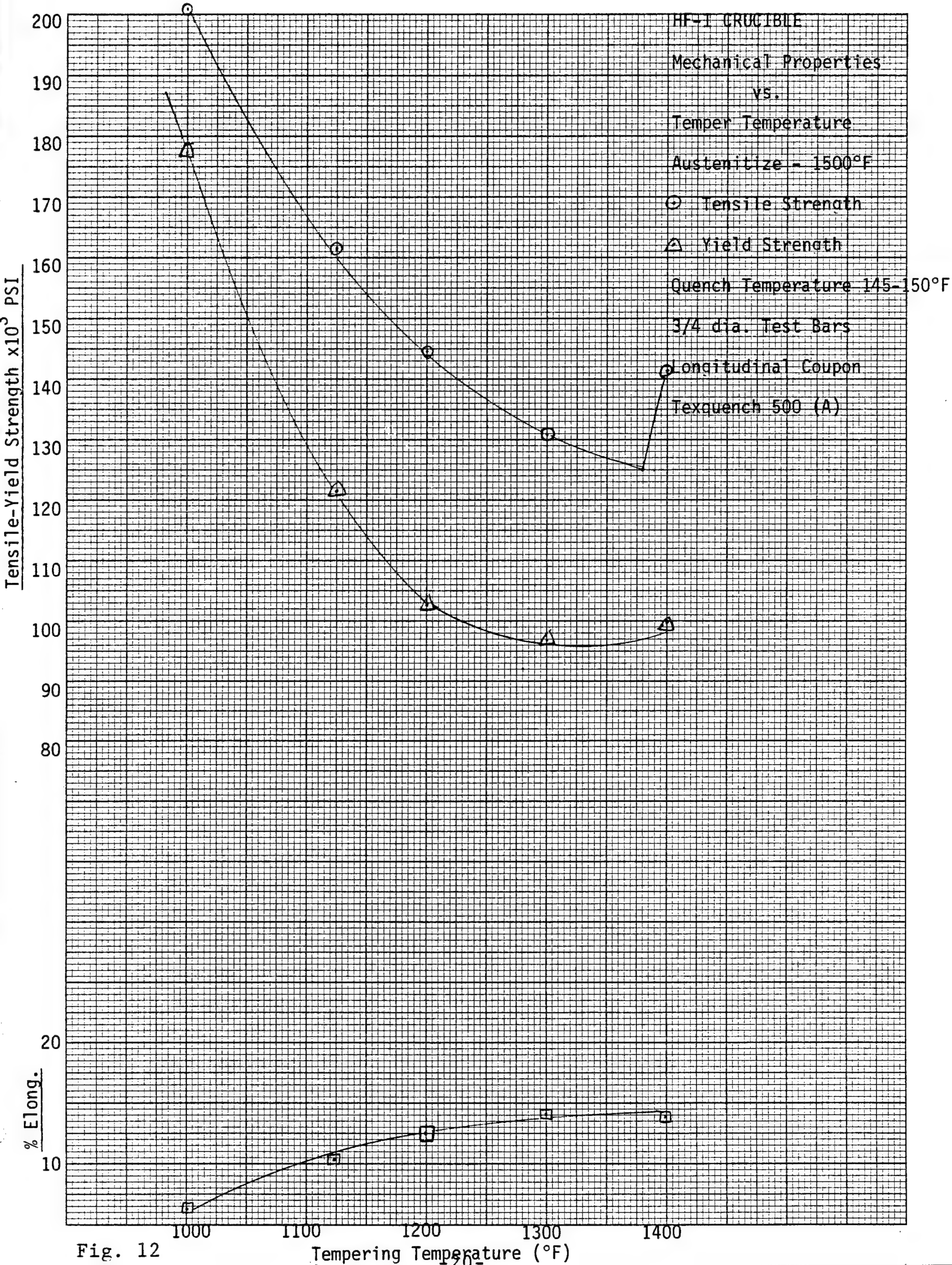
Figure 10 - Photomicrograph of untempered martensite platelet with micro-cracks. 500X

Figure 11 - Photomicrograph of untempered martensite platelets with micro-cracks. 500X

Figure 16 illustrates the compsite of the mechanical properties of the material from the four vendors.

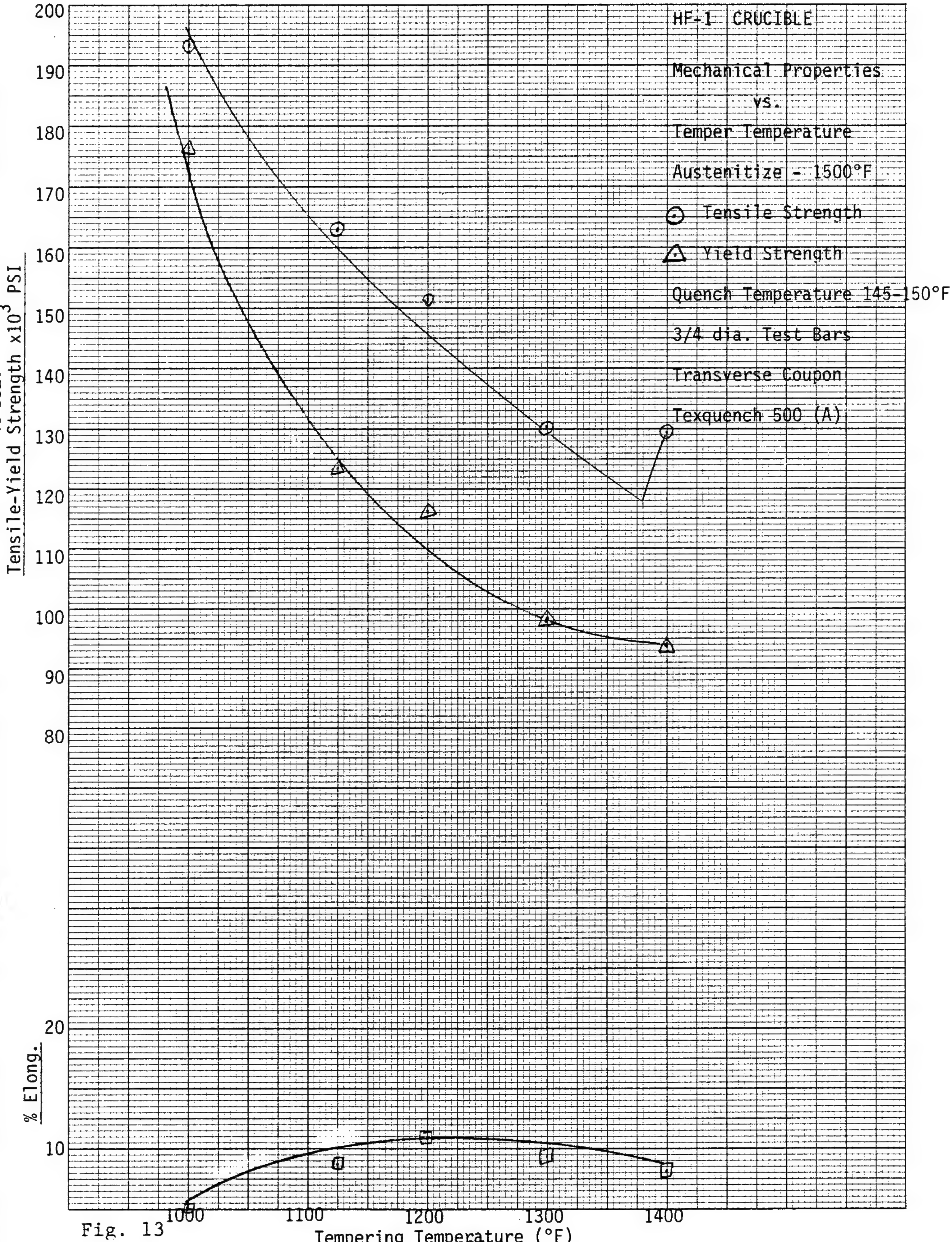
This figure shows that the steel from all four vendors will meet the minimum properties required for his scope of work.

Table 6 is in the mechanical data for both Crucible Steel and Bethlehem Steel (California).



HF-1 CRUCIBLE
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1500°F
Tensile Strength
Yield Strength
Quench Temperature 145-150°F
3/4 dia. Test Bars
Longitudinal Coupon
Texquench 500 (A)
Tensile-Yield Strength x10^3 PSI
% Elong.
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
1000
1100
1200
1300
1400
Tempering Temperature (°F)

Fig. 12


HF-1 CRUCIBLE
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1500°F
Tensile Strength
Yield Strength
Quench Temperature 145-150°F
3/4 dia. Test Bars
Transverse Coupon
Texquench 500 (A)
Tensile-Yield Strength x10^3 PSI
% Elong.
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
1000
1100
1200
1300
1400
Tempering Temperature (°F)
Fig. 13

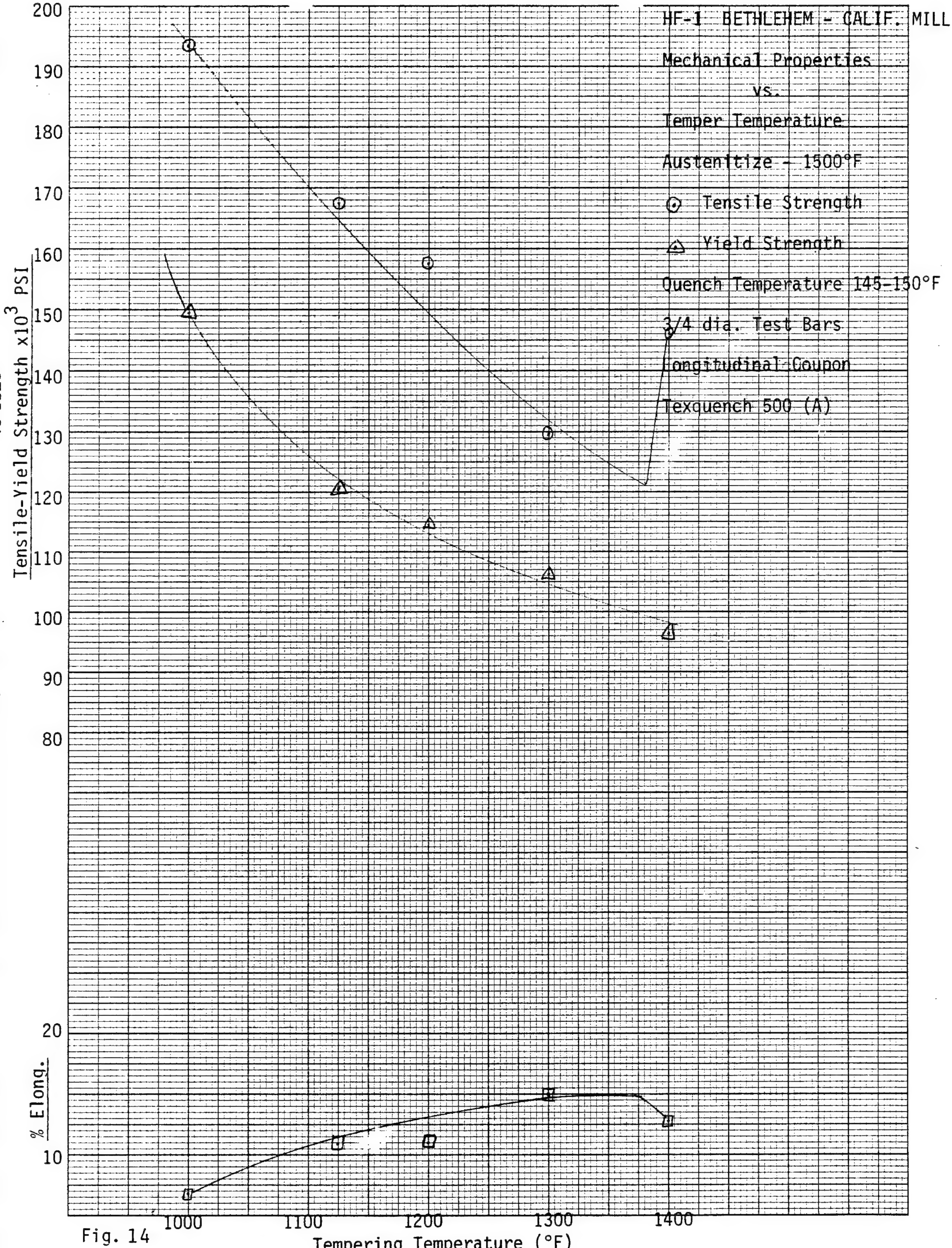

HF-1 BETHLEHEM - CALIF. MILL
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1500°F
Tensile Strength
Yield Strength
Quench Temperature 145-150°F
3/4 dia. Test Bars
Longitudinal Coupon
Texquench 500 (A)
Tensile-Yield Strength x10^3 PSI
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
% Elong.
1000
1100
1200
1300
1400
Tempering Temperature (°F)

Fig. 14

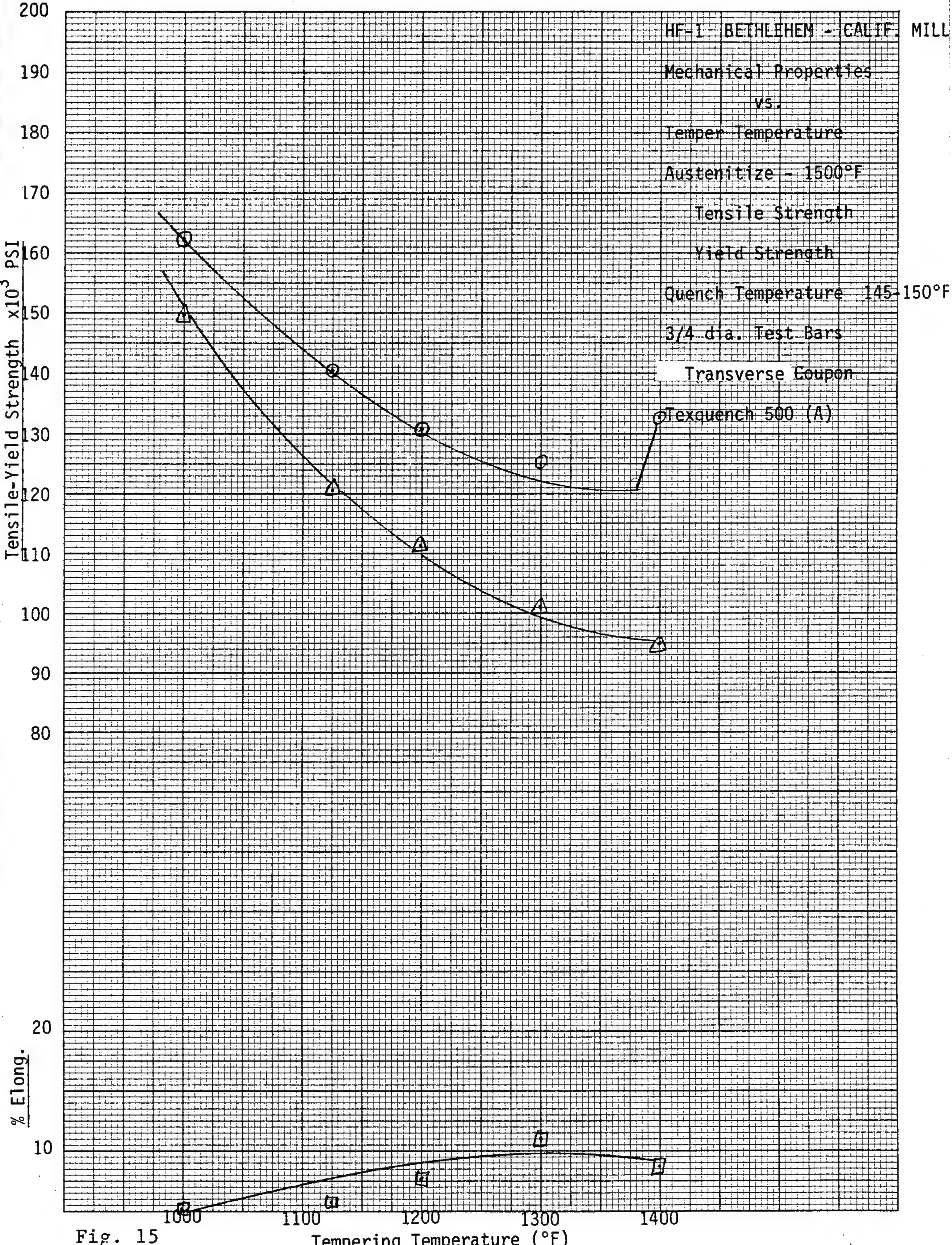

HF-1 BETHLEHEM - CALIF. MILL
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1500°F
Tensile Strength
Yield Strength
Quench Temperature 145-150°F
3/4 dia. Test Bars
Transverse Coupon
Texquench 500 (A)
Tensile-Yield Strength x10³ PSI
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
% Elong.
1000
1100
1200
1300
1400
Tempering Temperature (°F)

Fig. 15

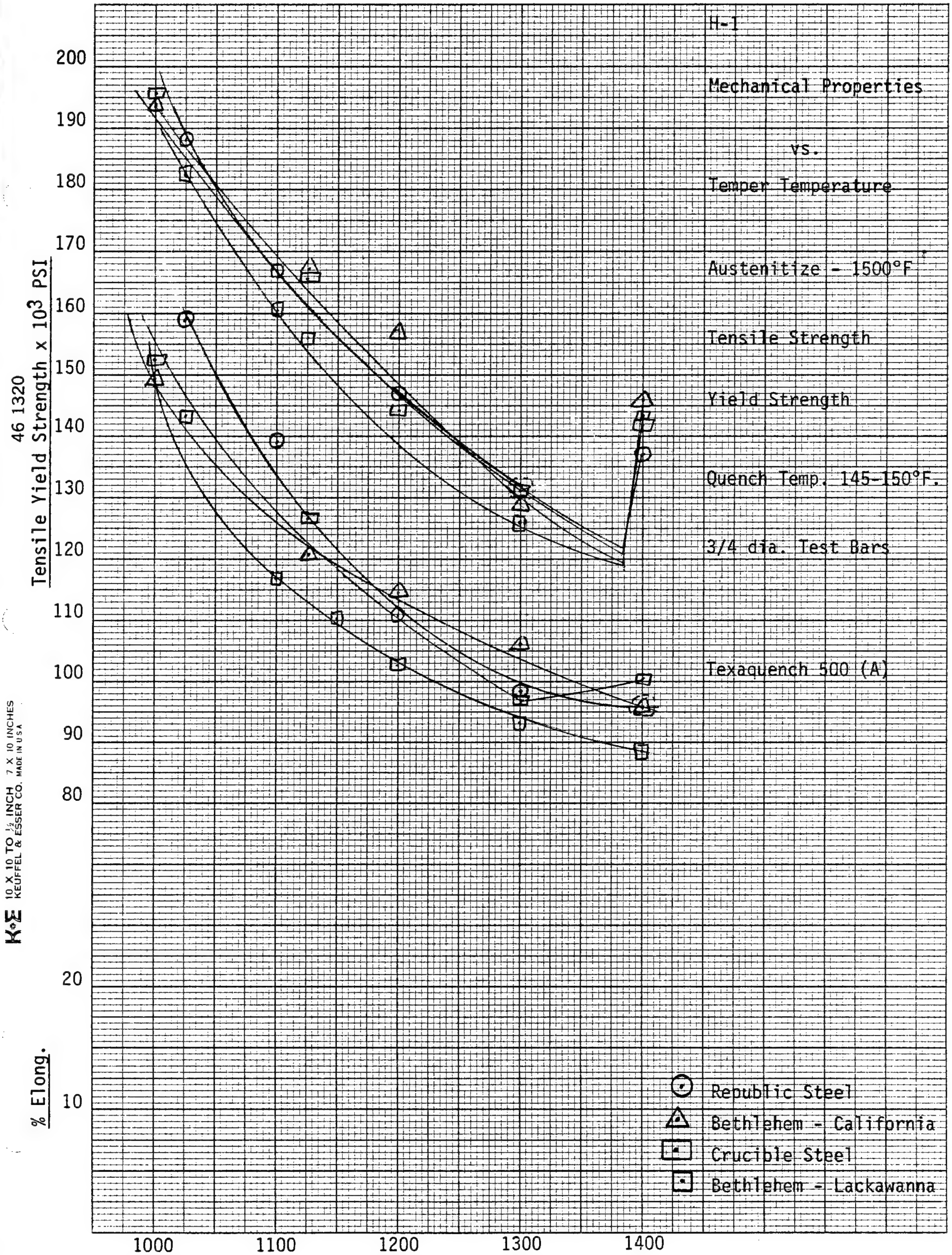

H-1
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1500°F
Tensile Strength
Yield Strength
Quench Temp. 145-150°F.
3/4 dia. Test Bars
Texaquench 500 (A)
Republic Steel
Bethlehem - California
Crucible Steel
Bethlehem - Lackawanna
Tensile Yield Strength x 10³ PSI
% Elong.
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
1000
1100
1200
1300
1400
Tempering Temperature (°F)
46 1320
K+E 10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

Fig. 16

TABLE 6

HF-1
Crucible Steel

Austenitizing °F	Austenitizing °C	Section	Yield Strength (psi)	Yield Strength (Mpa)	Tensile Strength (psi)	Tensile Strength (Mpa)	Elong. (%)	RA (%)
1000	538	L	152941	1054	195187	1346	6.4	18.7
1125	607	L	126462	872	165461	1141	10.4	26.5
1200	649	L	102863	709	144221	994	12.5	36.0
1300	704	L	96912	668	130990	903	14.0	35.7
1400	760	L	100212	691	141569	976	13.9	37.3
1000	538	T	176653	1218	193905	1337	5.1	5.0
1125	607	T	121406	837	161342	1112	8.6	6.0
1200	649	T	116736	805	151653	1045	11.0	14.8
1300	704	T	98140	677	130269	898	9.5	32.8
1400	760	T	94008	648	129132	890	8.0	6.1

HF-1
Bethlehem Steel (California)

Austenitizing °F	Austenitizing °C	Section	Yield Strength (psi)	Yield Strength (Mpa)	Tensile Strength (psi)	Tensile Strength (Mpa)	Elong. (%)	RA (%)
1000	538	L	149861	1033	193872	1337	6.9	13.8
1125	607	L	120873	833	167320	1153	11.0	24.7
1200	649	L	114400	789	157655	1087	11.5	22.7
1300	704	L	106180	732	129213	891	15.0	36.3
1400	760	L	95696	660	146055	1007	12.8	30.8
1000	538	T	149793	1033	162500	1120	5.1	4.3
1125	607	T	120582	831	141580	976	5.9	4.8
1200	649	T	111570	769	151343	1043	7.7	6.5
1300	704	T	101064	697	125851	868	11.1	16.6
1400	760	T	94595	652	132640	914	8.8	7.8

AUSTENITIC GRAIN SIZE

TABLE 7 - ASTM AUSTENITIC GRAIN SIZE

Crucible Steel	-	No. 4
Bethlehem Steel	-	No. 4

Photomacrographs are included in Appendix C.

CONCLUSION:

The following conclusions are a composite of those from the initial report and this supplemental report:

1. There is no significant difference between box-cooled or furnace-cooled material.
2. Material from all four sources will meet the desired mechanical properties.
3. Flame cutting must be forbidden.
4. HF-1 must be tempered immediately after quenching.
5. Severe surface conditioning by grinding is unacceptable.
6. All four heats of steel met the current specification (MIL-S-50783).

APPENDIX A

Photographs of Macro Cleanliness

MACRO CLEANLINESS

CRUCIBLE STEEL

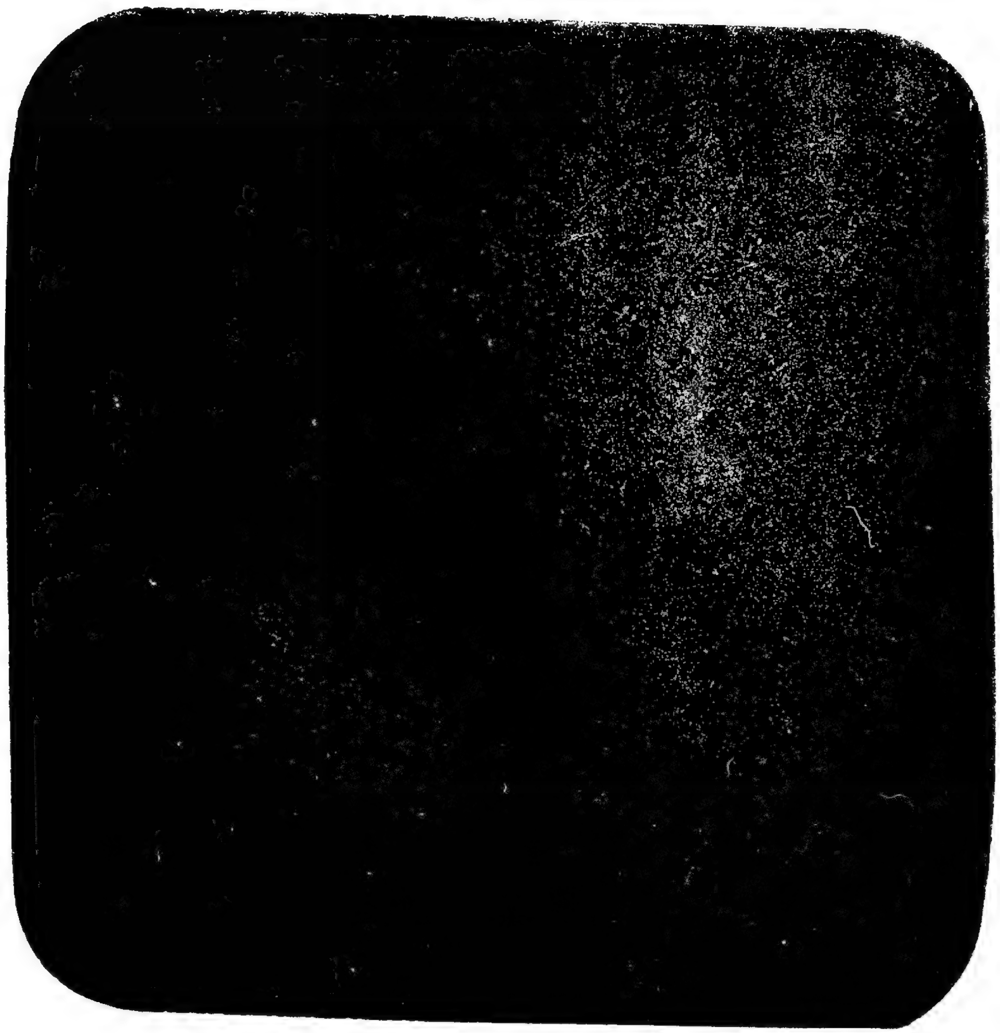


Figure 17 - Macro etched section of Crucible Steel billet.
1X

MACRO CLEANLINESS

BETHLEHEM STEEL

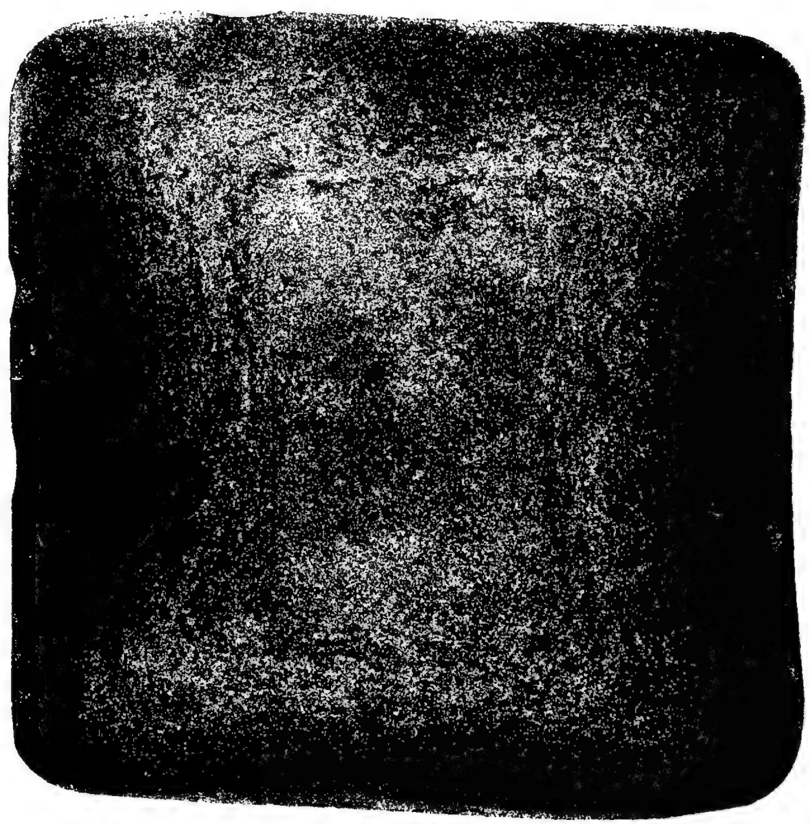


Figure 18 - Macro etched section of Bethlehem Steel billet.
1X

APPENDIX B

Billet Cross Section Hardness Pattern

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

27.7	29.3	29.3	30.1	29.6	30.3	29.4	31.5	30.7
28.8	28.3	30.7	29.9	30.0	31.6	29.5	29.0	30.5
28.0	29.2	28.6	30.0	30.4	30.2	30.3	28.5	30.8
27.6	28.6	29.2	29.5	29.3	29.1	30.8	28.4	29.9
28.1	27.9	28.7	29.4	28.5	30.5	28.4	29.2	30.0
29.0	28.0	28.6	28.6	29.2	29.1	26.7	29.4	29.1
29.0	28.1	30.0	29.7	29.0	30.1	28.2	29.6	29.0
29.9	29.8	30.6	29.6	29.8	28.7	29.2	29.1	29.3
29.2	29.8	29.6	29.4	29.4	28.7	29.9	29.7	30.1

Average (81 reads.) — 29.35 R_c

Standard Deviation ± 0.8895

TEST BLOCK (35.0 ± 1.0) – 34.6 R_c

Bethlehem Steel- California

TOLERANCES UNLESS OTHERWISE SPECIFIED		Chamberlain Chamberlain Manufacturing Corporation Scranton Army Ammunition Plant		
.000	± .005			
.00	± .010	TITLE BILLET		
.0	± .020			
FRAC.	± 1/32	DRN. S.C.	DATE 5-7-81	SCALE FULL
ANGLE	± 1°	CKD.		
		APPD.		

Figure 19. Bethlehem Steel Cross Section Hardness Patterns

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

30.8	31.7	29.3	30.3	31.1	31.5	30.8	29.6	30.5	31.3
31.4	30.7	30.9	31.0	30.6	30.8	31.2	30.6	30.2	31.0
31.7	30.6	30.5	30.5	30.7	30.9	31.0	30.5	31.0	30.9
30.5	31.1	30.8	30.9	31.1	30.8	31.2	30.9	30.7	30.7
30.6	31.1	30.5	30.8	31.1	30.6	31.2	30.8	30.9	30.4
30.3	30.5	30.9	30.2	30.5	31.0	30.3	30.9	30.5	30.7
31.4	30.2	30.7	29.5	30.1	29.7	28.4	28.8	29.8	30.5
30.0	30.0	30.2	30.2	29.2	28.4	28.6	29.3	29.9	30.4
29.1	29.6	29.5	29.9	29.3	29.3	30.1	29.7	29.6	30.3
28.9	29.2	29.5	29.4	29.9	29.9	29.3	28.9	29.5	29.6
29.5	28.6	28.8	28.9	29.9	29.5	29.8	29.5	28.9	29.7

Rockwell Test Block
C 35.0 ± 1.0 R_c
5-7-81 35.0 (5 Test.

Mean 30.225 R_c
σ 0.7849

Crucible Steel

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. LJF	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Figure 20. Crucible Steel Cross Section Hardness Patterns

APPENDIX C

ASTM GRAIN SIZE

ASTM GRAIN SIZE

BETHLEHEM STEEL

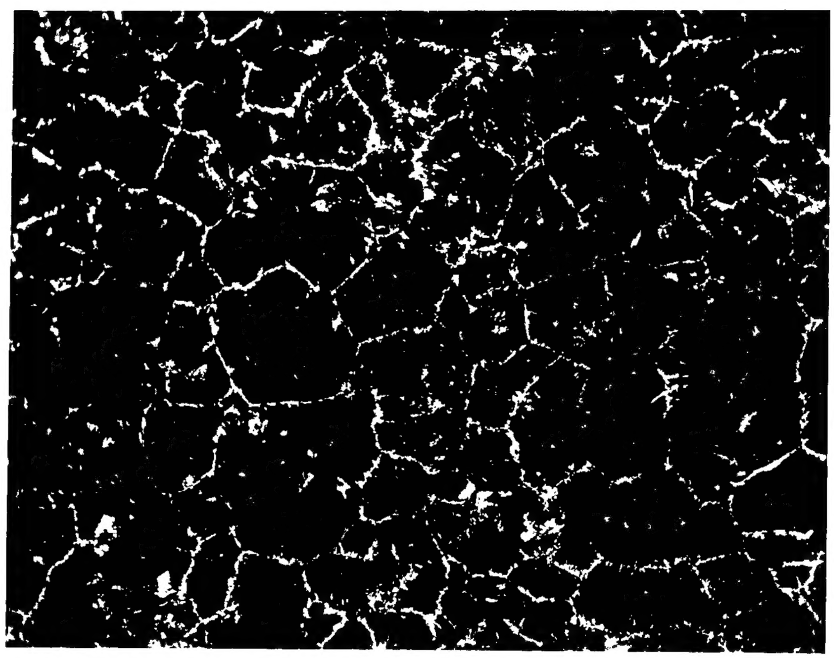


Figure 21 - ASTM Grain size of Bethlehem Steel material.
125X

ASTM GRAIN SIZE

CRUCIBLE STEEL

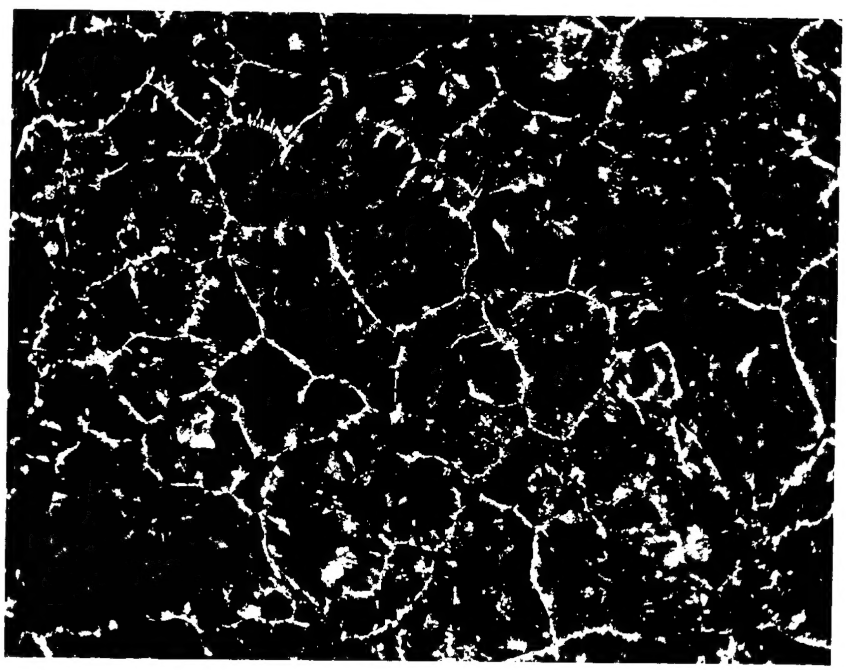


Figure 22 - ASTM Grain Size of Crucible Steel material.
125X

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U. S. Army TRADOC Systems Analysis Activity
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